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Irrigation systems also fall into two categories: peasant irrigation works and technical irrigation works. The former have existed throughout Southeastern Asia for more than a thousand years. In recent times scientifically trained engineers have designed large-scale systems with concrete weirs and locks. Fields solely dependent upon impounded rain water produce one rice crop a year, whereas irrigated fields often yield two crops. If even with irrigation only one crop can be produced, yet the irrigation system assures proper water control, whereas without it irregularities in the course of the rainy season may damage, or destroy, the crop.

Wet fields are protected against erosion by leveling, terracing, and dyking. But how does continued cropping affect the fertility of wet-rice fields? Diverse environments and cultural practices in Southeastern Asia create considerable differences in this respect. Much of the paddy land of the Philippines, Indochina, Thailand, Malaya, and Burma has lost a good deal of its original fertility because the peasants have not used manures, fertilizers, or crop rotation. In many instances, however, soil fertility has been preserved by the mineral matter dissolved in the irrigation water and by the silt deposited on those fields that are supplied with irrigation water coming from streams. The value of the water and silt depends, of course, upon the nature of the parent material from which it is derived. Rivers from a young volcanic region supply much richer water and silt than do those that drain a mountain region consisting of sedimentary rock or granite. For this reason, the Irrigation Service of the Netherlands Indies before making final plans for a new irrigation system takes samples of water and silt carried by rivers at different times of the year. The samples are analyzed in order to determine their influence upon the soil to be irrigated. A river found to be carrying water and silt that would lower the value of paddy land would be eliminated as a source of irrigation water, or its use would be limited as much as possible.

Irrigated fields of which the water supply does not contain minerals in quantities necessary for continuous satisfactory plant growth and paddy land that depends exclusively upon rain, both require other techniques for maintaining fertility. In many regions cultivators cut the rice stems just far enough below the ear to allow bundling. This practice makes possible the return of the rest of the plant matter to the soil. From this it is only one more step to work household refuse into the ground together with ashes of burned rubbish, rice husks, leaves, and manure.

As stable manure is not available in adequate quantities, intensive studies of the application of green manures to the cultivation of rice have been made in a number of countries of Southeastern Asia. A recent article by W. Bally reviews the results of these studies.[14] In a few rice-growing regions the peasants, on their own initiative, have learned to use legumes to improve rice soil. In wet fields the decomposition of green manure takes place under anaerobic conditions, and the final product is ammonia. Since

[14] Bally: "The Employment of Green Manures," 1936, pp. T10–T31.

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rice takes up nitrogen in the form of ammonia, the value of green manures on wet-rice fields is apparent.[15] In the Indies, *Crotolaria* species are the most frequently used green manures, the favored one being *Crotolaria juncea* L.; but *Phaseolus lunatus* L., *Dolichos lablab* L., and *Pachyrrhizus erosus* Urban are also used. The peasants of the Red River delta in Tongking are in the habit of working into the ground the wilted matter of a number of legumes that have been grown primarily for seed. The peasants of the province of Nam Dinh have developed a technique that may be unique. They push handfuls of indigo branches into the ground between the rows of rice a few days after the latter has been transplanted, for they believe that indigo is superior to pig manure or human excreta. In Indochina rice-growers frequently cultivate green manure, especially *Crotolaria* species, on dry fields and carry it to the rice fields at the time when these fields are being prepared for the seedlings. A green manure used exclusively in a few districts of the delta land of Tongking is the small aquatic plant, *azolla*.[16] Certain villages, thanks to favorable circumstances, have specialized in the growing of azolla to sell to the surrounding country, while other villages reproduce the plant until sufficient quantities of green manure have been obtained to cover all needs. The life cycle of azolla is completed in the months from November to April or May. Only the villagers of LaVan know the secret of maintaining and multiplying the plant during the hot season. They guard this secret jealously since it is the basis of their livelihood.

Further studies are needed to establish which varieties of green-manure plants are best suited to the various environmental conditions. It is important to find plants that grow rapidly and can be sown when the rice is still on the field, just after the water has been drained off to allow the grain to ripen. Experiments should also be made in the timing of the application of green manure. Should it be early, or just before the transplanting of the seedlings? Should it be on dry or on wet land?

Crop rotation also has its place as a means of keeping up the fertility of wet-rice fields. This practice seems to be better developed and more prevalent in Java than in any other country of Southeastern Asia. Extensive areas of *sawah*, as the Javanese call their wet riceland, are planted with dry-field crops such as maize, legumes, and other vegetables during the dry season, a practice that has a beneficial effect upon the soil. This form of double cropping is probably better than raising two rice crops in one year, because—although a different variety of rice is chosen for each season—both make essentially the same demands upon the soil; whereas a peanut crop, for example, grown during the dry season will enlarge the nitrogen content of the soil. In some areas of Java lowland rice is rotated

[15] Imperial Bureau of Soil Science: Tropical Soils in Relation to Tropical Crops, 1936, p. 11.

[16] For a map showing the extent of the use of azolla, see Gourou: Les paysans, 1936, p. 392. For further discussion see Nguyên-cong-Tiêu: "L'azolle," 1930, B, pp. 335–350 (also in *Proc. Fourth Pacific Science Congress, Java, 1929*, Vol. 4, 1930, pp. 355–370).

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with sugar or tobacco grown under plantation management. But is the high fertility of the soil due to this crop rotation, or is it rather the result of the heavy application of commerical fertilizer and the thorough cultivation of the soil under Western management?

In no country of Southeastern Asia is there so great a variety or so intensive a use of commercial fertilizers as in Japan.[17] In general, the peasants of Southeastern Asia lack money for commercial fertilizers. In Indochina local phosphates are within reach of some of the Annamese, but the costs of imported fertilizers are prohibitive. In Java, although attempts to make possible the use of fertilizers through the agency of public credit institutions were successful in some special instances, not more than one per cent of the cultivated area received any commercial fertilizer in 1939. On the other hand, estimates indicate that more than 1,000,000 hectares of sawah have a phosphate deficiency and that a moderate application of phosphate would augment the yield by 25 to 50 per cent.[18]

The Agricultural Advisory Service was able to raise the productivity of wet-rice fields in West Java by about 10 per cent. It encouraged the peasants to use fertilizer on seedbeds, to sow rice more thinly on the beds (thus producing stronger seedlings), and to plant the seedlings in rows so that weeding could be done with a special instrument, the *landak* (Fig. 59). This weeder was developed in Japan. During the years immediately preceding 1939, these improvements in West Java resulted in an increase in output of unhusked rice amounting to 300,000 quintals, or 30,000 metric tons, with a value of nearly 1,000,000 guilders. This shows that some improvements in cultivation may increase production without a great capital outlay.[19]

Java may be compared only with southern China and with Japan in the cleanness of its rice fields. The Filipino does not pay much attention to weeding. The Malayan, Thai, Cambodian, Cochinchinese, and Filipino rice farmers have more flooded riceland per capita at their disposal than the people of Java and can thus afford to cultivate their land less intensively.

Irrigation Problems

Peasant irrigation works usually take care of the fields of only one village or of a small group of people who have joined together for the specific purpose of building and maintaining an irrigation system. These works consequently are small and usually inadequate, but nevertheless they de-

17 "The chief commercial fertilizers used in Japan are pressed herrings, pressed sardines, dried sardines, other fish cakes, bone meal, soybean cake, rapeseed cake, cottonseed cake, other vegetable-oil cakes, ammonium sulphate, calcium cyanamide, calcium phosphate, and potassium phosphate. Calcium phosphate and ammonium sulphate are probably the most representative chemical fertilizers."—Wickizer and Bennett: The Rice Economy, 1941, p. 252, footnote 33.

18 Departement van Economische Zaken: Voedselproblemen, 1940, p. 28.

19 *Ibid.*, pp. 27–28.

[See p. 117, category 116. -- Analyst]

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climate characterized by heavy rainfall often concentrated in one season, and it will, unless checked, lead to the exhaustion of the fertility of the soil at a comparatively rapid rate in the tropics. In Southeastern Asia permanent dry fields are usually found on sloping ground exposed, much more than in the case of garden or wet-rice land, to the danger of erosion. Garden land is protected by dense stands of perennials, while terracing and dyking guard wet fields against destructive erosion. The terracing of dry fields is one of the most effective ways to control the loss of soil, but, since terracing requires so much labor, we find terraced dry fields only in densely settled regions, and even there the peasants often will not undertake this additional labor unless they are urged to do so by the authorities. As long as there is enough land available, the peasants prefer to let dry land recuperate by lying fallow for short periods rather than to protect it by terraces; but with the increasing density of population and the consequent shrinkage in the size of individual farms this practice is no longer possible (Figs. 61–64). [1]

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As early as the second half of the nineteenth century, K. F. Holle, the agricultural adviser in the Netherlands Indies, constantly stressed the need of controlling erosion on dry fields. Following his advice, the government, in Article 5 of the 1874 Ordinance on Alienation of Domain Forest Land, stipulated that permission to clear domain land on sloping terrain be given to the peasants only on condition that they terrace the slopes and thus control erosion.[50]

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The need for the terracing of slopes became especially apparent in Java in the coffee lands that the peasants had to plant under the forced-culture system. Many of these lands were completely exhausted after a few years, and Holle showed that this rapid exhaustion occurred because the topsoil had been washed away by heavy rains. In 1873 he wrote detailed instructions for the terracing and cultivation of coffee lands.[51] However, Holle's instructions and the stipulations of the Ordinance of 1874 were subjected to criticism and often ignored. In 1889, therefore, the Government of the Indies asked Forester Berkhout to investigate the practical results of the application of terracing to tegalans. Berkhout's report summarizes the arguments for and against terracing; these still make interesting reading.[52] The arguments against terraces on tegalans were put forth as follows:

1. The people are not used to terracing dry land.
2. Terracing demands more labor.
3. It reduces productivity in the first year if the land is rather steep and the humus layer thin.

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[50] Article 5 reads: "Dat bij hellend terrein zoo er gevaar bestaat voor afspoeling van de bouwkruin, de aanleg geschiede terrasgewijze, en voorts onder zoodanige voorwaarden als plaatselijke omstandigheden wenschelijk maken." Ontginnings-Ordonnantie, *Staatsblad 1874*, No. 79.

[51] Nederlandsch-Indische Maatschappij: Handleiding, 1873.

[52] Berkhout: "Terrassenaanleg," 1892, pp. 139–141.

[1] [See p. 117, cat. 116--Analyst]

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The Agricultural Advisory Service of the Netherlands Indies for many years carried on experiments with green manures and recommended a variety suitable for different conditions, but the main obstacle to the application of their research was the difficulty of introducing green manure into a crop rotation. Some of the green manures used in Java are *Crotolaria anagyroides* H. B. and K., *Crotolaria usaramoensis* Baker, *Tephrosia candida* DC. and *Tephrosia vogelii* Hook., *Calopogonium mucunoides* Desv., *Centrosema pubescens* Benth., *Centrosema plumierii* Benth., and *Mimosa invisa* Mart. Green manure requires a relatively large amount of water in order to produce the desired foliage. If there is sufficient water, the peasants can also grow other crops such as legumes, which supply food as well as fertilizer. Most of the peasants of Java have so little land that they cannot afford to sacrifice a single food crop from a field in spite of the probability of an increased yield after the green manure has been plowed under. Although it is preferable to grow green manure unmixed with other plants, the planting of a green manure crop among the food crops is recommended where land is scarce. This is done in Java, especially in maize and cassava fields. The specific green manure that is chosen should meet the following conditions:[59]

1. It should have a rapid growth,
2. An abundant production of leaves,
3. No excessive development that might harm the main crop,
4. An absence of climbing or trailing stems;
5. The plant should have deep roots with many nodules;
6. It should not become woody too easily—as herbaceous plants decompose much more quickly; and
7. It should be immune from the diseases and insects that attack the main crop.

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Another agricultural practice common to many parts of the world, especially the tropics, is mixed cropping, which seems to bring in its train some of the advantages of rotation.[60] Nicol stresses the great importance of having leguminous plants grown among non-leguminous plants. He points out that the legume component in the mixture provides nitrogen to the non-legume.[61] In various parts of India—for example on the Bombay Deccan—bulrush millet (*Pennisetum typhoideum* Rich.) is grown with various legumes. This can be done year after year without greatly affecting the fertility of the soil. No crop rotation is practiced here. The proportion of bulrush millet to legumes varies according to the quality of the land; the poorer the land, the smaller the proportion of millet and the larger the proportion of legumes. Wallace wrote in 1887:

The growth of mixed crops is a widespread practice which is well worth consideration and study. . . . The advantages . . . are distinctly great. . . . There is

[59] International Institute of Agriculture: Use of Leguminous Plants, 1936, p. 60.
[60] Willis: Agriculture in the Tropics, 1914, p. 29.
[61] Nicol: "Mixed Cropping," 1935, p. 189.

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but one explanation of the existence of these practices, viz., that they have been found advantageous after long experience and much careful consideration on the part of a body of workers who, for power of observation and an intelligent interest in and knowledge of every day occurrences, would put to shame those classes which hold a corresponding position in educated Europe.[62]

Well known is the American Indian's practice of interplanting maize, beans, and squash. Chinese and Japanese peasants practice mixed cropping widely, and we may observe it almost everywhere in Southeastern Asia. Intensive mixed cropping in the garden culture of Java has already been described (see above, pp. 43–45), but there is relatively little interplanting of legumes with non-legumes. On dry fields the peasants of some parts of Java are accustomed to interplant cassava and maize—both, however, non-legumes. Whereas maize can be harvested after 100 days, cassava needs up to a year or more of growth. Cowpea (*Vigna sinensis* Savi), Goa bean (*Psophocarpus tetragonolobus* DC.), Lima bean (large) (*Phaseolus lunatus* L.), and hyacinth bean (*Dolichos lablab* L.) are also interplanted with cassava. On tegalans in Bali, in 1941, I observed the following crops grown with upland rice: *Eleusine indica* Gaertn., sesame (*Sesamum indicum* L.), and pigeon pea (*Cajanus cajan*). This last enriches the soil as a result of its large production of leaves as well as by the nitrogen in its nodules.

Kaserer has noted that there is little or no interpenetration of plant roots of the same species when they are grown together, whereas a significant degree of root interpenetration takes place when two different species are grown in close association, the degree of interpenetration increasing with the degree of dissimilarity. In one experiment, for example, a legume and a non-legume showed the maximum amount of root interpenetration, the explanation apparently being that one plant takes up the nutrients produced, or made available, by the other.[63] If these observations are correct we have here a scientific argument for the value of mixed cropping. Further studies are needed to determine the desirability of improving and extending it in specific areas.

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Another important method of improving the fertility of dry fields is the use of compost. Vegetable composts are employed extensively in India and Africa. The masters at making compost from household refuse, vegetable waste, and human excreta are the Chinese, who cling to this method of fertilization wherever they practice truck farming in the neighborhood of urban centers in Southeastern Asia. Fungi and bacteria are used to break down suitable mixtures of vegetable and animal wastes. A method that was developed in India is the "Indore process" in which, "by arranging these mixtures in the proper way, and by watering and turning them, to supply moisture and air, the waste materials are transformed in about ninety days into a finely divided humus rich in the foods required by grow-

[62] Wallace: India in 1887, 1888, pp. 196 and 198.
[63] Kaserer: "Beobachtungen," 1911, pp. 1022–1030.

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ing crops. The process can be adapted to climate by manufacture either in shallow pits or low heaps."[64]

Dry-Field Crops Cultivated by Peasants

The list of dry-field crops cultivated in Southeastern Asia is rather large, but there are regional variations. Cassava, for example, is commonly grown on tegalans in Java (2,300,000 acres), whereas it is unimportant in Sumatra, Borneo, the Philippines (40,000 acres), Malaya (24,000 acres), and Indochina (75,000 acres). The most important dry-field crops are upland rice, maize, cassava, sweet potatoes, peanuts, soy beans and other pulses, tobacco, and sugar cane, all of which are annuals. Of the first four, only upland rice is a native of Southeastern Asia, whereas the other three are natives of the New World and were introduced into Southeastern Asia by the Spaniards in the sixteenth century.

TABLE IV—CHEMICAL COMPOSITION OF CASSAVA AND IMPORTANT CEREAL FLOURS

	CASSAVA (PER CENT)	MAIZE (PER CENT)	WHEAT (PER CENT)	RICE (PER CENT)
Moisture	10.75	13.41	13.65	13.12
Protein	0.87	7.56	12.35	9.85
Crude fat	1.19	2.79	1.75	0.88
Ash	1.24	1.78	1.81	1.51
Crude fiber	6.12	3.19	2.53	0.63
Carbohydrates	79.83	71.27	67.91	74.01

Source: The Cassava Industry in the Philippines, 1939, p. 7.

The inhabitants of Southeastern Asia have long relied upon root crops, fruits, leaves of various plants, and wild roots and tubers gathered in the forests, as well as upon rice. Scheltema refers to a number of early statements which indicate that "rice was not yet the principal food for a large portion of the native population [of Java] as late as the first part of the 19th century and that the rice diet has become much more important in the course of the past hundred years" as a result of the great extension of the cultivation of irrigated rice fields.[65] If it is correct that the rice consumption per capita increased during the past century, the opposite trend has been evident during the present century. For a while the increase in the area of irrigated land was great enough to allow for a larger rice production, but with the steadily increasing pressure of population the peasants now have to depend more and more upon unirrigated land. Thus the production of dry-field crops is gaining in importance.

Authorities in Southeastern Asia have been especially worried over the increase of cassava production and consumption. Because of the exhaustion of the soil fertility on many dry fields, the growing of upland rice and

[64] Worthington: Science in Africa, 1938, p. 387.
[65] Scheltema: The Food Consumption, 1936, p. 10.

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land. An example is *mongo* (*Phaseolus mungo* L.), grown in Pangasinan and Batangas. Alarmed by the poor rice crops in 1940 and the difficulty of importing rice from Indochina and Thailand, the Philippine Bureau of Plant Industry, early in 1941, started to distribute seed of quick-growing dry-field crops, especially maize and legumes, in order to supplement the nation's rice bowl. But the average Filipino farmer is reluctant to accept this new practice, because "it is not the custom"—a powerful argument not to be easily overcome.

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Dry-Field Crops Cultivated by Plantations

The discussion thus far has been limited to the native cultivation of dry land and to annual crops. However, extensive areas of non-irrigated land are occupied by perennial crops that are grown on plantations owned by Westerners. The crops produced include tea, coffee, cacao, quinine, rubber, palm oil, coconuts, kapok, sisal, and other fibre plants. Some of these crops were cultivated for a long time without the proper measures being taken to protect the soil against accelerated erosion. Although the detrimental effects of plantation agriculture in Ceylon and southern India are notorious in the plantation history of southern Asia, results were just as disastrous in Malaya and in the Netherlands Indies. Westerners, accustomed to clean cultivation or clean weeding in the temperate zone, carried this practice over into the tropics, with the result that soil erosion was very severe on steep slopes and led to great losses in soil fertility. Today, however, these mistakes have been recognized; there is hardly a plantation that has not adopted measures to protect sloping land against erosion and level land against soil exhaustion. The planters of Java were the pioneers in this field, introducing or developing most of the protective measures. These measures include contour drains, silt pits, contour ridges, terraces, hedges, shade trees, and especially cover crops. The use of these measures varies according to the crop, or crops, produced and according to climate, soil, and slope; but the purpose of all of them is to encourage an effective ground cover and to check the rate of water run-off. The financial depression of the 1930's—resulting in the need for very strict economy and a decrease in production costs—has helped considerably to reduce the amount of clean weeding and to convince conservative planters of the value of preserving a ground cover, litter, and mulch. Such measures help not only to retard erosion but also to enrich the soil. The first Western planter who broke away from the custom of keeping the ground of his plantation free from weeds was L. M. Tyl, who in the years 1890–96 developed the "weed-system" and thus introduced the idea of a ground cover into plantation circles of Southeastern Asia. But it took many years before his idea was generally accepted. It is interesting to note here that the Asiatic-owned plantations and the small holdings producing perennial crops, such as rubber, usually did not practice clean weeding. This, in the early days, was regarded by European observers as a sign of laziness and

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poor management, but, as has been so often the case, the Westerners were finally forced to admit the soundness of Oriental cultivation practices.

As we have seen, there are two principal means of protecting the soil between tree crops: by allowing the growth of indigenous plants or weeds (in other words the development of a natural mixed cover), or by establishing a pure cover of leguminous plants, many of which came originally from the New World. Rubber planters in Malaya seem to have had more success with the first method, which has been called "the forestry method of cultivation" or "rubber forestry." [67] Of course, the growth of indigenous plants or weeds must be controlled, and this is done by slashing the undergrowth from time to time. Frequently it is necessary to practice selective weeding in order to suppress undesirable plants and encourage more valuable ones.

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Much research has been directed toward the study of leguminous cover crops which supply nitrogen, as well as foliage for green manure. This research was started in 1910 in the Botanical Garden at Buitenzorg. Some of the cover crops that have proved especially valuable and are widely used on modern plantations are *Calopogonium mucunoides* Desv., *Centrosema pubescens* Benth., *Centrosema plumierii* Benth., *Desmodium* species, *Tephrosia candida* DC. and *Tephrosia vogelii* Hook., *Mimosa invisa* Mart., *Cassia* species, and *Vigna oligosperma* Backer.[68] Several of these have already been mentioned in the foregoing discussion on the use of green manure crops in native agriculture.

Because a number of perennials such as tea, coffee, and cacao are commonly grown under shade trees, many writers seem to believe that these plants need shade. This may be true in part, but more important is the fact that the shade trees protect the soil against excessive losses of moisture and undesirable changes in soil composition, texture, and structure and thus prevent a reduction of the quantity of humus in the soil. Most of the commonly used shade trees are legumes which, in addition to shade, supply litter and nitrogen and help to increase the moisture-holding capacity of the soil, thus reducing the danger of erosion. *Erythrina micropteryx* Poepp., *Erythrina lithosperma* Miq., *Leucaena glauca* Benth., *Albizzia moluccana* Miq., *Albizzia chinensis* Merr., *Albizzia falcata* Backer, *Pithecellobium dulce* Benth., or Manila tamarind, and *Peltophorum pterocarpum* Backer are especially useful in this respect.

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[67] Haines: "The Uses and Control of Natural Undergrowth," 1934.

[68] For a very extensive list of cover crops, green manures, and shade trees, see Heyne: De nuttige planten van Nederlandsch-Indië, Vol. 3, 1927. See also International Institute of Agriculture: *op. cit.*